

***Achieving the 2050  
Greenhouse Gas Reduction Goal***

***How Far Can We Reach with Energy  
Efficiency?***

**Arthur H. Rosenfeld, Commissioner  
California Energy Commission  
(916) 654-4930  
ARosenfe@Energy.State.CA.US**

**[http://www.energy.ca.gov/commission/commissioners/rosenfeld.  
html](http://www.energy.ca.gov/commission/commissioners/rosenfeld.html)**

**or just Google “Art Rosenfeld”**

# Introduction

- Focus will be on 2030 as my crystal ball is hazy after that
- Will the world find motivation to reduce CO<sub>2</sub>?
  - Hurricanes (more frequent, further North), Fall fires and droughts
- The UN or a “super-G8” must cooperate in this effort
  - With financial incentives for China, India, ... for “clean” coal.
- Cap and Trade systems will probably not be sufficient to keep levels at 450 ppm or below
- To modify behavior (e.g. land use, travel) switch to a Carbon Tax where you can tax “bads” to pay for “goods” (e.g. social security or medical insurance)
  - ~\$3/gallon of gasoline, ~\$300/ton of CO<sub>2</sub>, or ~20 cents/kWh
- “Free Trade” for lower carbon fuels. e.g.
  - Elimination of \$0.50 per gallon on imported ethanol

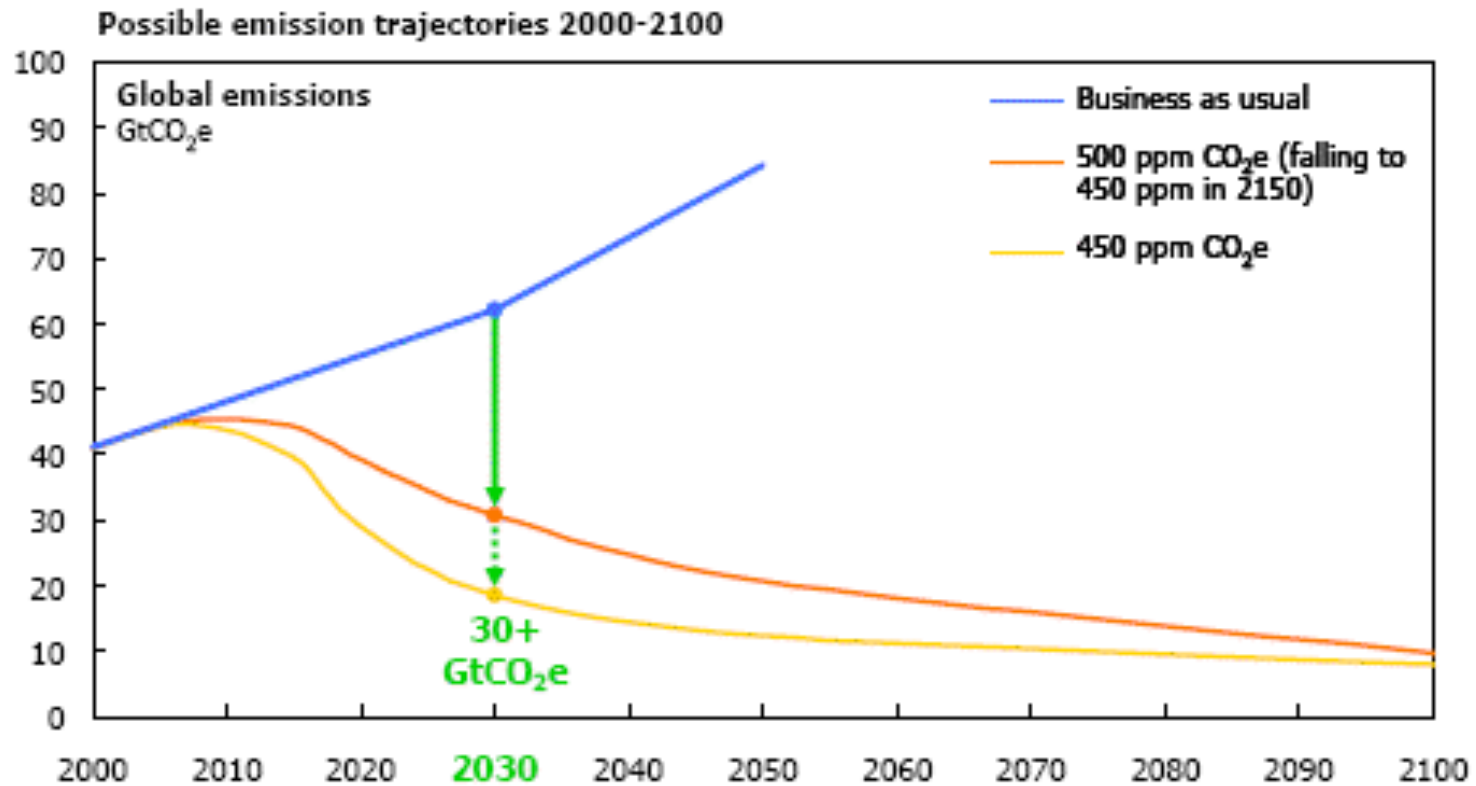
## Illuminating Space vs. the Street



To maintain 50/50 chance of staying below 2°C implies stabilizing <450ppm GtCO<sub>2</sub>e  
(at least 30 Gt reduction by 2030)

**Possible emission trajectories 2000-2100 of global Emissions:** from Hal Harvey,  
“Design to Win,” California Environmental Associates, **adapted from Stern Review**

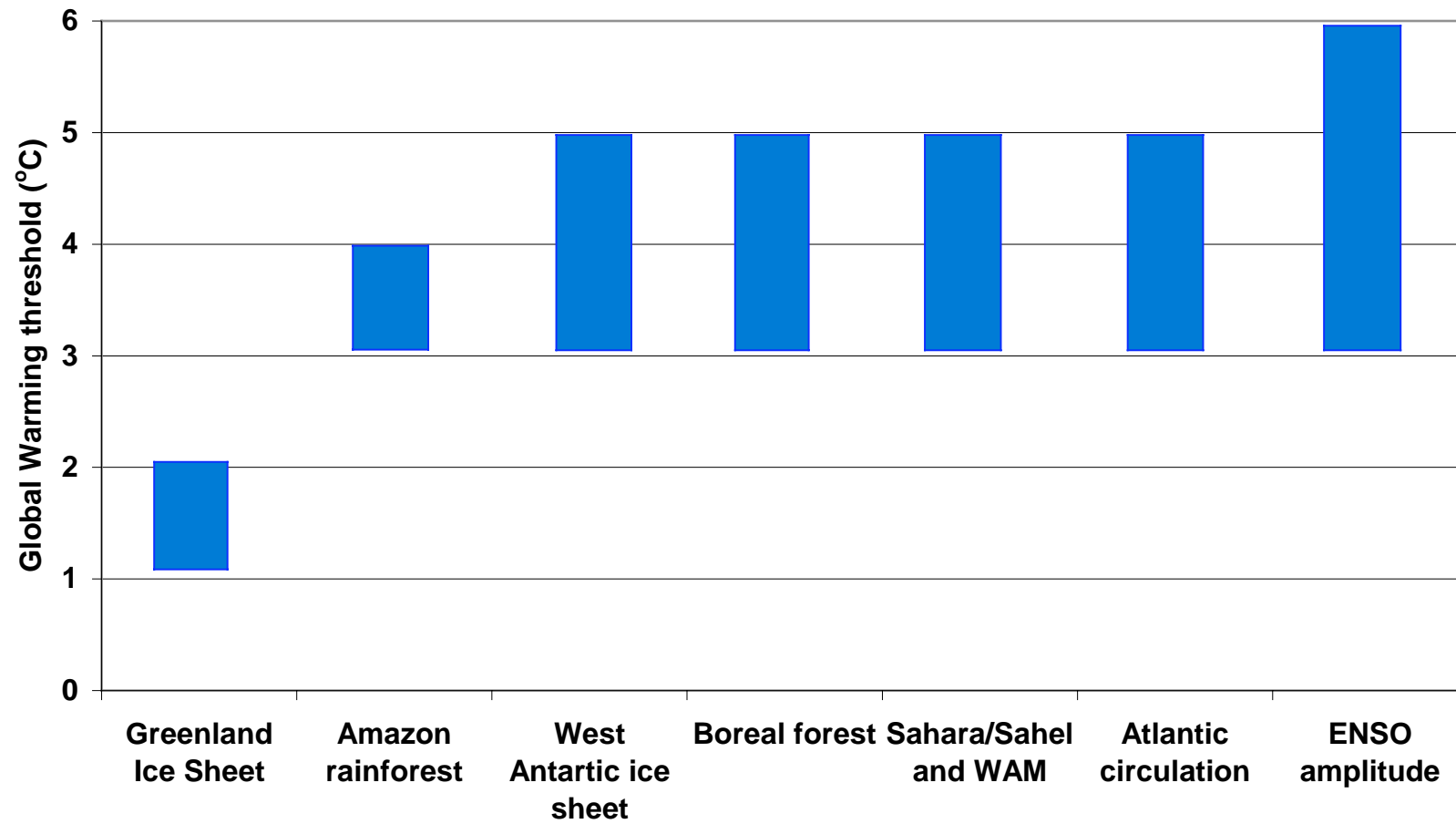
**FIGURE 6: Stabilizing Emissions Requires a Minimum 30 Gt**



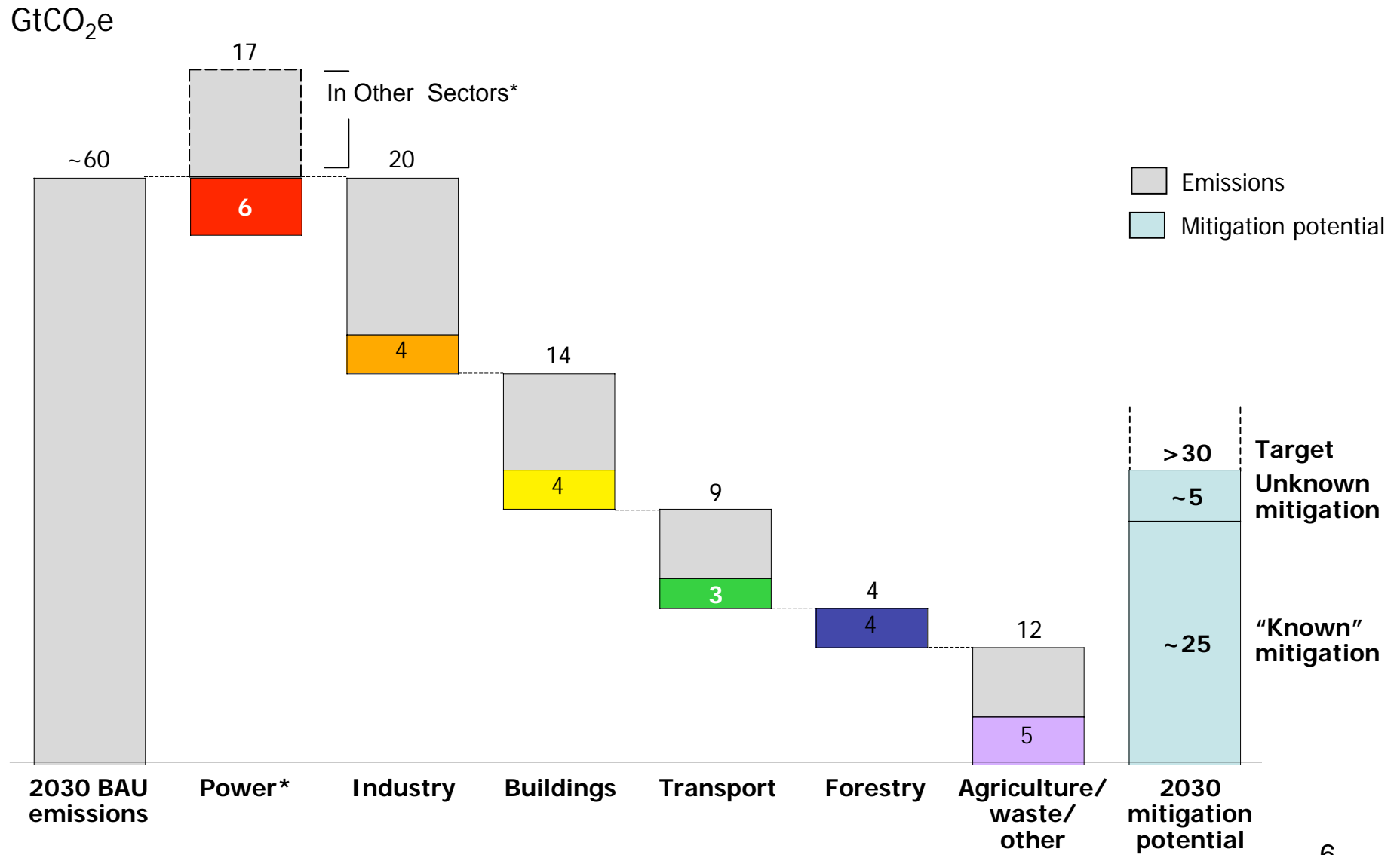
Source: Adapted from Stern Review, 2006; BAU emissions ~WEO A2 scenario; 450 ppm budget range based on Stern and preliminary IPCC analysis

## Tipping Element

(from Tipping Points of Gradual Climate Change, Timothy M. Lenton, U of East Anglia)



# Available interventions in 6 sectors Worldwide could secure 5/6 of target based on *Design to Win*



\* Power sector emissions (but not mitigation potential) counted in industry and building sectors

# Conservation Supply Curves Explained

- Start with conservation supply curves for electricity, natural gas, gasoline, etc
- Annual benefit = yearly saved bills – annualized cost of measure
- Then convert kWh or therms or gallons or ... to CO<sub>2</sub> avoided
- Note that shaded areas are dollars saved or spent (depending if below or above the x-axis)

See NAS “Policy Implications of Greenhouse Warming” 1992, App. B

- **Policy Implications of Greenhouse Warming:** Mitigation, Adaptation, and the Science Base (1992) Committee on Science, Engineering, and Public **Policy** (COSEPUP ... [books.nap.edu/books/0309043867/html](http://books.nap.edu/books/0309043867/html)

## McKinsey Quarterly

# A **cost curve** for greenhouse gas reduction

*A global study of the size and cost of measures to reduce greenhouse gas emissions yields important insights for businesses and policy makers.*

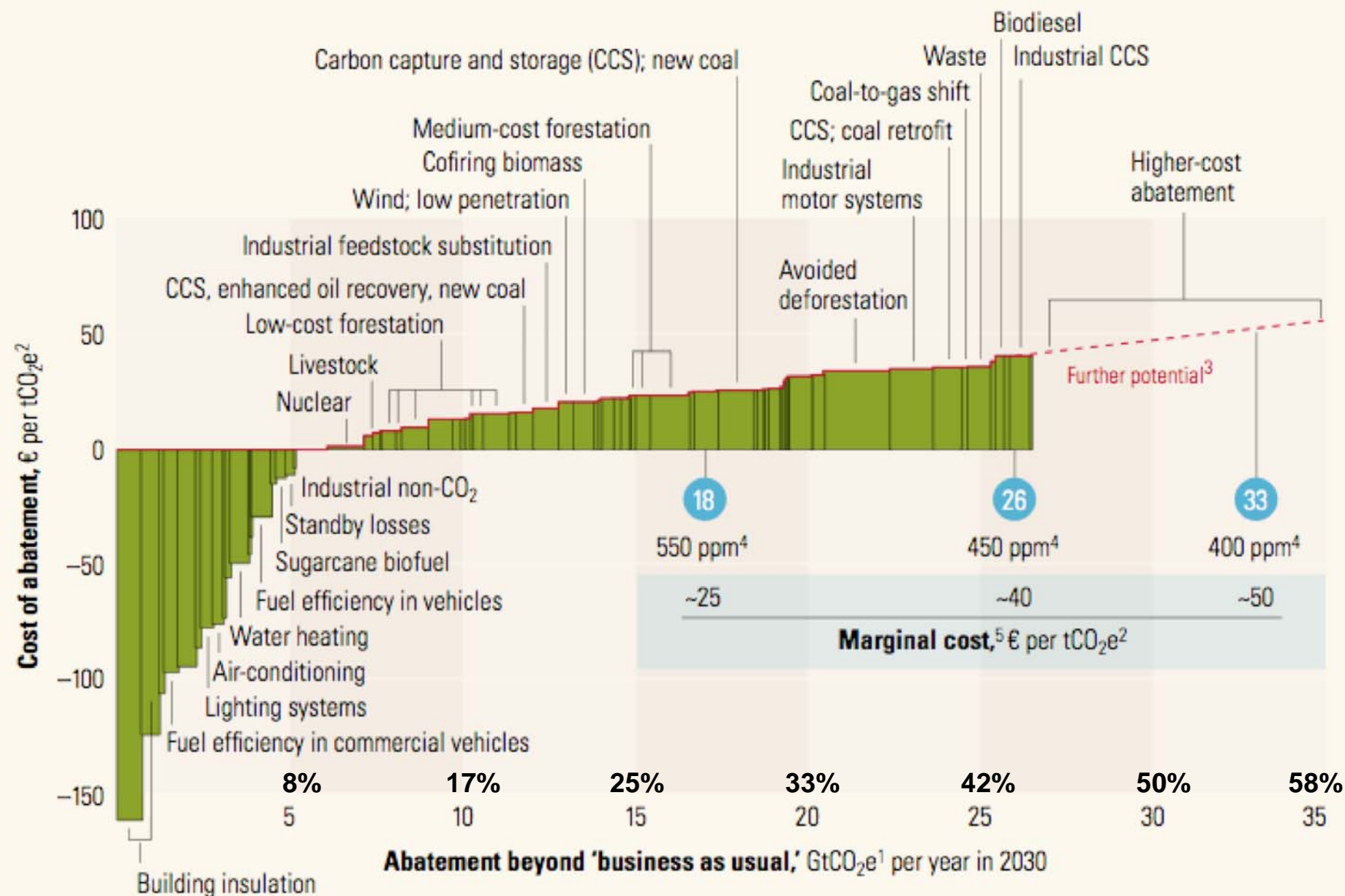
**Per-Anders Enkvist, Tomas Nauc  r,  
and Jerker Rosander**

[http://www.mckinseyquarterly.com/Energy\\_Resources\\_Materials/  
A\\_cost\\_curve\\_for\\_greenhouse\\_gas\\_reduction\\_abstract](http://www.mckinseyquarterly.com/Energy_Resources_Materials/A_cost_curve_for_greenhouse_gas_reduction_abstract)



Global cost curve for greenhouse gas abatement measures beyond 'business as usual'; greenhouse gases measured in GtCO<sub>2</sub>e<sup>1</sup>

● Approximate abatement required beyond 'business as usual,' 2030



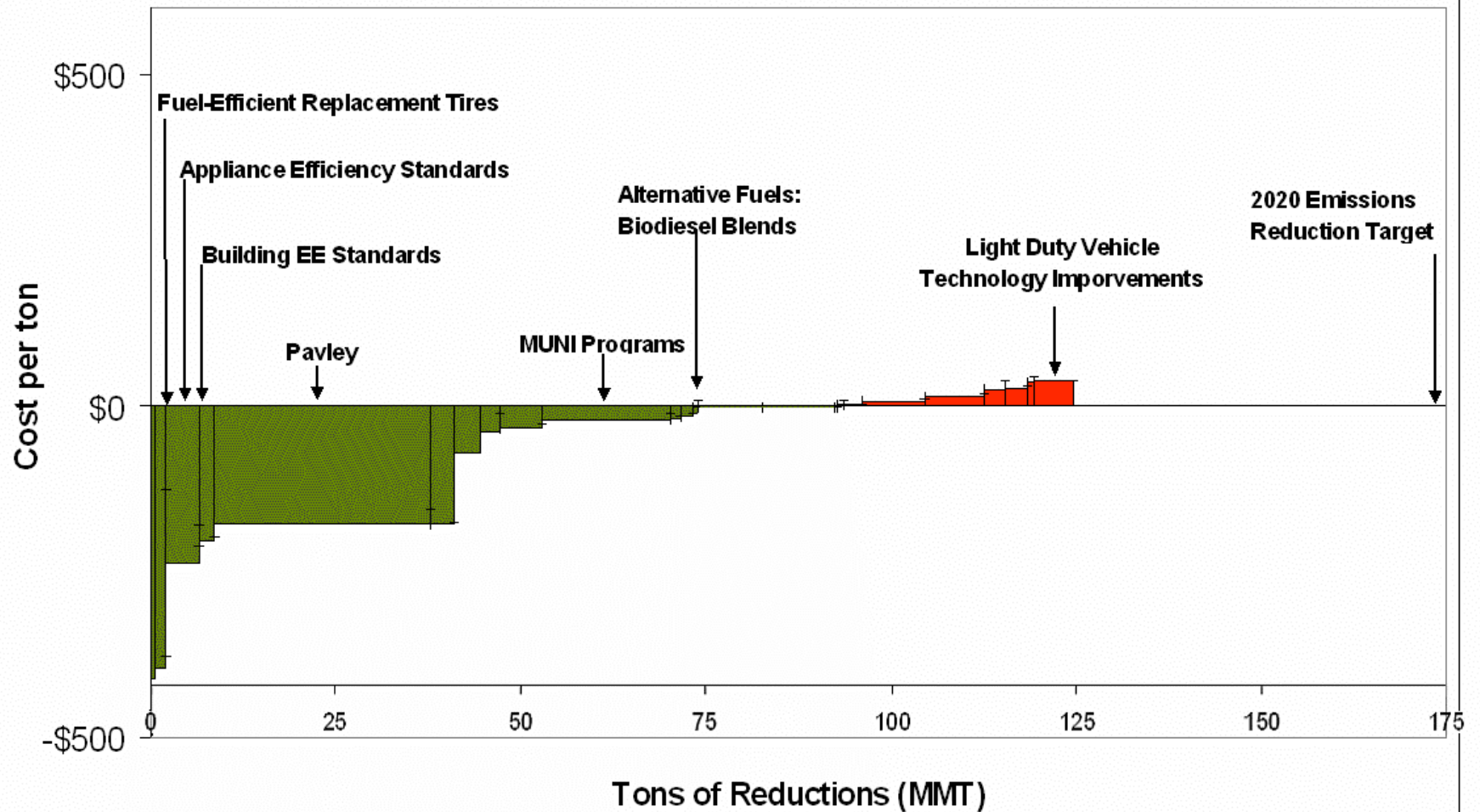
# Turning to California

- AB 32 CO2 Goals:
  - 1990 levels by 2020
  - 80% below 1990 levels by 2050
- Where are we headed?

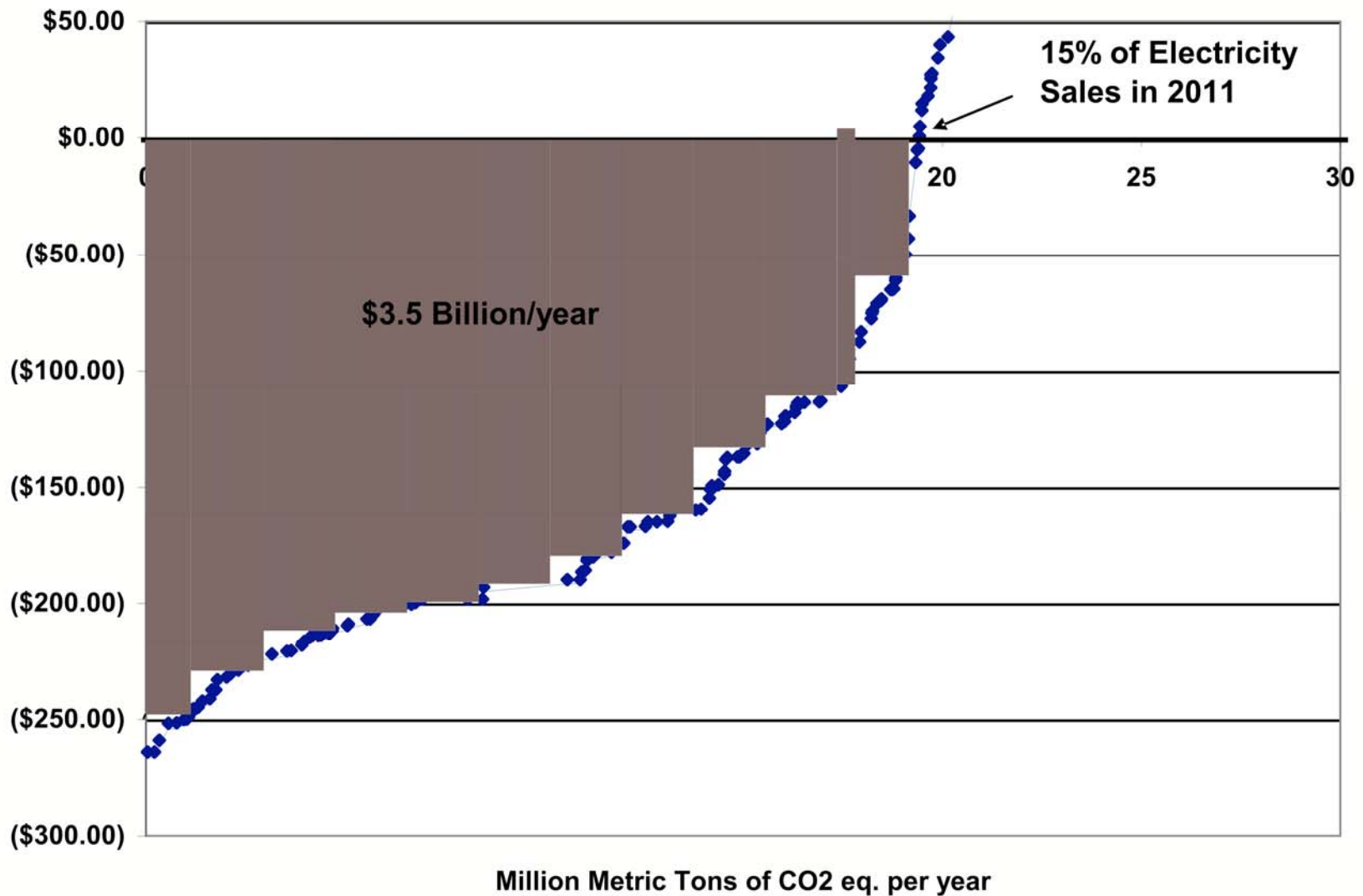
	<b>1990</b>	<b>2000</b>	<b>2010</b>	<b>2020</b>	<b>2030</b>	<b>2040</b>	<b>2050</b>
CALIFORNIA Population (million)	30	34	39	44	49	54	60
growth rate (historic and projected)		1.3%	1.4%	1.2%	1.1%	1.0%	0.9%
CO2 Business as Usual (MtCO2 eq.)	436	480	530	585	647	714	789
CO2 to Meet AB 32 Goals	436	480	486	436	320	204	87
growth rate to Meet AB 32		1%	0.1%	-1%	-5.3%	-5.3%	-5.3%

Note: CO2 historic and projected data continue to change, consider these as estimates

## Illustrative GHG Reduction Strategies



**Supply Curve for CO<sub>2</sub>, Conserved thru Energy Efficiency in Electricity Sector in California - Potential in 2011 at 1 kwh = 0.454 kg of CO<sub>2</sub>**



# Cool Urban Surfaces and Global Warming

Hashem Akbari

Heat Island Group

Lawrence Berkeley National Laboratory

Tel: 510-486-4287

Email: [H\\_Akbari@LBL.gov](mailto:H_Akbari@LBL.gov)

<http://HeatIsland.LBL.gov>

**PALENC Conference, September 27, 2007; Crete, Greece**

# Acknowledgement

- Co-authors
  - Dr. Arthur H. Rosenfeld, Commissioner, California Energy Commission
  - Dr. Surabi Menon, Staff Scientist, Lawrence Berkeley National Laboratory

Research was funded by the Public Interest Energy Research (PIER) Program, California Energy Commission.



# White is 'cool' in Bermuda



and in Santorini, Greece





# Cool Roof Technologies

Old



flat, white



pitched, white

New

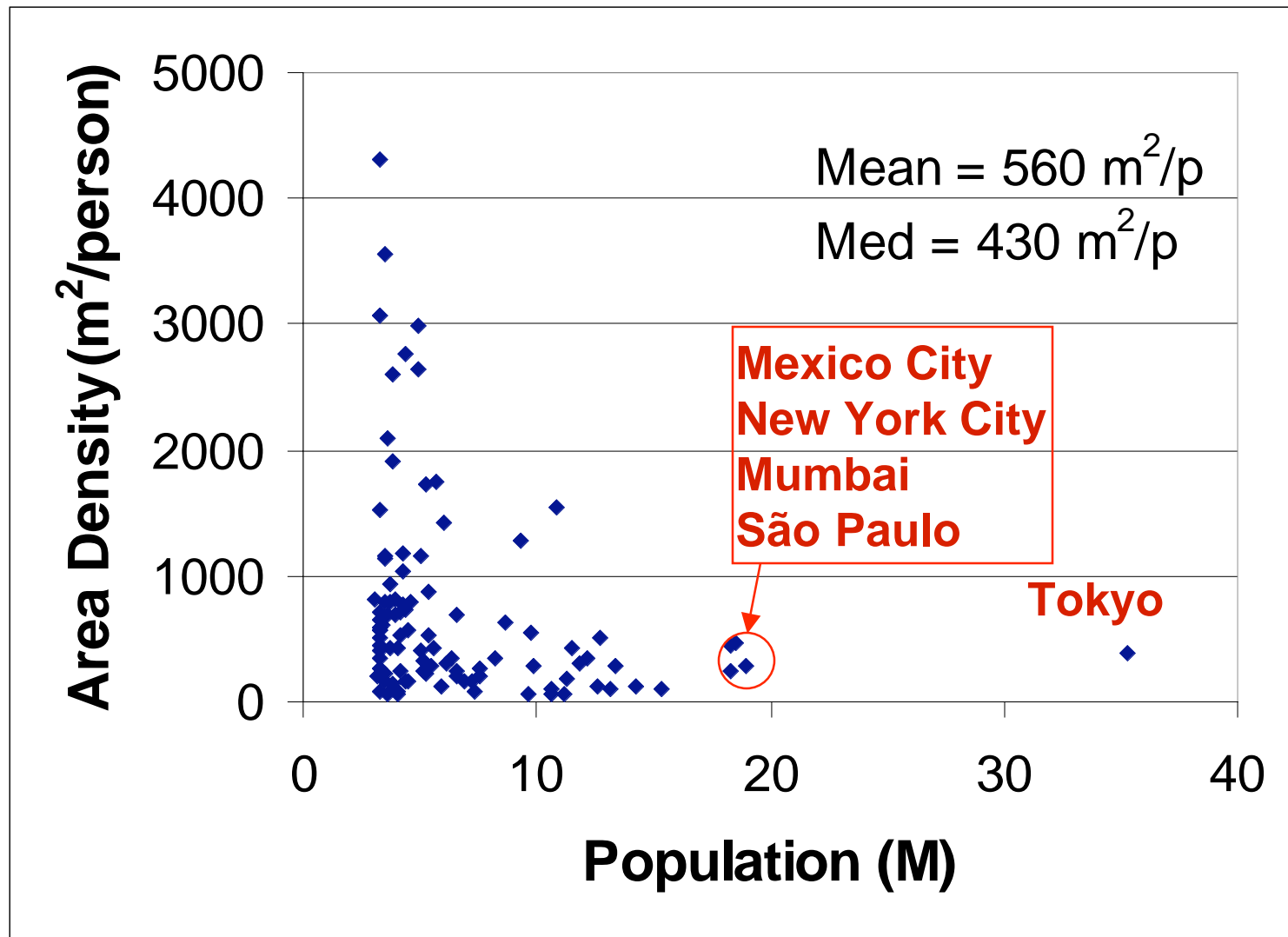


pitched, cool & colored

# Cool Surfaces also Cool the Globe

- Cool roof standards are designed to reduce a/c demand, save money, and save emissions. In Los Angeles they will eventually save ~\$100,000 per *hour*.
- But higher albedo surfaces (roofs and pavements) directly cool the world, quite independent of avoided CO<sub>2</sub>. So we discuss the effect of cool surfaces for tropical, temperate cities.

100 Largest Cities have 670 M People



## Radiative Forcing (RF) of 1 tCO<sub>2</sub>.

- Myhre et al. (1998), for well mixed CO<sub>2</sub>, quote  
$$RF [W/m^2] = 5.35 \ln(1 + \Delta C/C).$$

Inserting  $\Delta C = 1 \text{ t CO}_2$ , we find

$$RF(\text{worldwide}) \sim 1 \text{ kW}.$$

so, enough white roof to reflect 1 kW (on average, night, day, adjusted for clouds) will offset

1 ton of CO<sub>2</sub>. “Enough” turns out to be 30 m<sup>2</sup>.

So each 200 m<sup>2</sup> white roof offsets ~7 t CO<sub>2</sub>.

## Dense Urban Areas are 1% of Land

- Area of the Earth =  $508 \times 10^{12} \text{ m}^2$
- Land Area (29%) =  $147 \times 10^{12} \text{ m}^2$  [3]
- Area of the 100 largest cities =  $0.38 \times 10^{12} \text{ m}^2 = 0.26\%$  of Land Area for 670 M people
- Assuming 3B live in urban area, urban areas =  $[3000/670] \times 0.26\% = 1.2\%$  of land
- But smaller cities have lower population density, hence, urban areas =  $2\%$  of land =  $3 \times 10^{12} \text{ m}^2$  [4]
- Dense, developed urban areas only 1% of land [5]

## Potentials to Increase Urban Albedo is 0.1

- Typical urban area is 25% [6] roof and 35% [7] paved surfaces
- Roof albedo can increase by 0.25 for a net change of  $0.25 \times 0.25 = 0.063$
- Paved surfaces albedo can increase by 0.15 for a net change of  $0.35 \times 0.15 = 0.052$
- Net urban area albedo change at least 0.10

## Effect of Increasing Urban Albedo by 0.1

- Roof area =  $0.25 [6] \times 1.5 \times 10^{12} \text{ m}^2 [5] = 3.8 \times 10^{11} \text{ m}^2 [8]$
- Carbon reduction of cool roofs  
=  $33 \text{ kg CO}_2/\text{m}^2 [1] \times 3.8 \times 10^{11} \text{ m}^2 [8] = 12 \text{ GT CO}_2 [9]$
- Paved area =  $0.35 [7] \times 1.5 \times 10^{12} \text{ m}^2 [5] = 5.3 \times 10^{11} \text{ m}^2 [10]$
- Carbon reduction of cool pavement  
=  $20 \text{ kg CO}_2/\text{m}^2 [2] \times 3.8 \times 10^{11} \text{ m}^2 [10] = 7.5 \text{ GT CO}_2 [11]$
- Carbon reduction of cool roofs and cool pavements  
= 20 GT CO<sub>2</sub> [12]
- 20 GT CO<sub>2</sub> is half of the annual world emission of 40 GT CO<sub>2</sub>eq --- a reprieve of 6 mo with NO emissions.

## Cooler cities as a mirror

- Mirror Area =  $1.5 \times 10^{12} \text{ m}^2$  [5]  $\times (0.1/0.7)$  [ $\delta$  albedo of cities/  $\delta$  albedo of mirror]  
=  $0.2 \times 10^{12} \text{ m}^2$  {This is equivalent to an square of 460 km on the side}

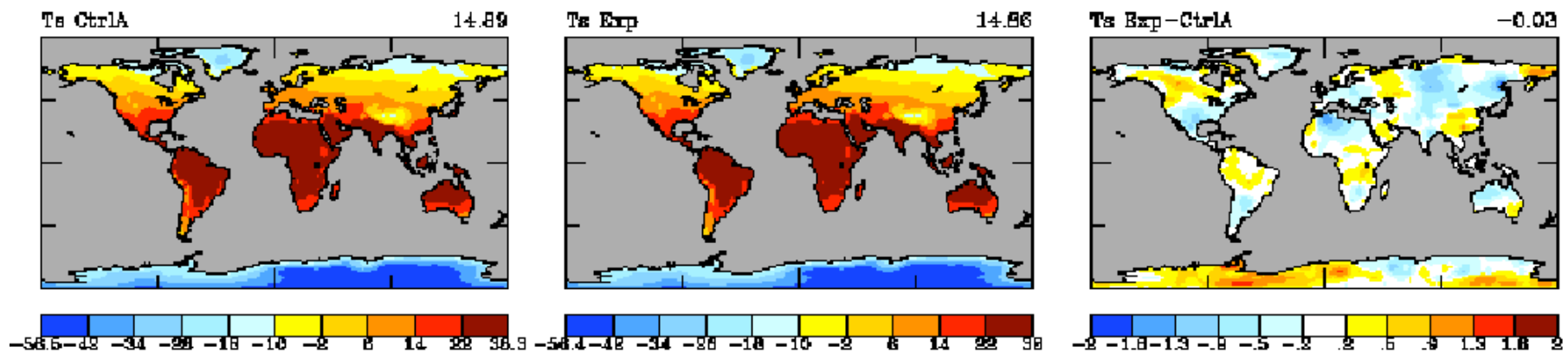


## Equivalent Value of Avoided CO<sub>2</sub>

- CO<sub>2</sub> currently trade at ~\$25/ton
- 20 GT worth \$500 billion, for changing albedo of roofs and paved surface
- Cooler roofs alone worth \$300B
- Cooler roofs also save air conditioning (and provide comfort) worth five times \$300B
- Let developed countries offer \$1 million per large city in a developing country, to trigger a cool roof/pavement program in that city

## Effect of Increasing Urban Albedo by 0.1 on Global Temperature is -0.01K

- Using Harte's equations (*Consider a Spherical Cow*, pages 166, 174), the change in air temperature in lowest 1.8 km = 0.011K
- Using Hansen et al. (1997), the change in air temperature is = 0.016K (checks Harte's)



# References

- Hansen et al. 1997: J Geophys Res, 102, D6(6831-6864)
- Myhre et al. 1998: Geophys Res Let, 25, 14(2715-2718)
- Harte 1988: *Consider a Spherical Cow*, pages 166, 174